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Evaluation of the RCRA (Resource Conservation and Recovery Act) Extraction Procedure - Lysimeter Studies with Municipal/Industrial Wastes

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EVALUATION OF THE RCRA EXTRACTION PROCEDURE - LYSIMETER STUDIES WITH MUNICIPAL/INDUSTRIAL WASTES

Environmental Engineering Division
Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180

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A study was initiated to determine the accuracy with which the Extraction Procedures (EP), employed in the regulations promulgated under Section 3001 of the Resource Conservation and Recovery Act (40 CFR 26.124), simulates the leaching an industrial waste would undergo when codisposed with municipal refuse in a non-secure landfill.

The simulation of the codisposal of municipal solid waste (MSW) with untreated industrial waste (IW) was initiated October 28, 1980. The 0.91 x 1.8 m cylindrical test cells were designed to simulate sanitary landfill environments. The 5 types of industrial waste were oil reclaiming clay, petroleum refinery incinerator ash, paint manufacturing sludge, solvent refining sludge, and tannery waste. Fifteen test cells were loaded providing triplicate samples of each IW leachate. All test cells have received an 8.4 liter (1.26 cm infiltrated rainfall) addition of deionized water each week. Leachate samples have been collected from the MSW and beneath the MSW-IW wastes on a monthly basis. Results of analyses for 7 inorganic parameters from leachate collected below the MSW and below MSW-IW are reported for 5 sample periods.

The increase in concentration of the metals in the blow MSW-IW is compared to the change in concentration produced in the EP extract. When the published EP concentration criteria (100 time primary drinking water standards) for the specific metals was exceeded, the test cells also showed a concentration that exceeded the criteria. The EP concentrations are generally lower than the concentration of the same constituents from the same wastes in the test cells.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, reassuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report presents the results of the evaluation of the RCRA Extraction Procedure and a review of the test implementation. It provides basic data that will contribute to our knowledge regarding the Extraction Procedure and the land disposal of untreated industrial waste codisposal with municipal waste.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

A study was initiated for the U. S. Environmental Protection Agency to determine the accuracy with which the Extraction Procedures (EP), employed in the regulations promulgated under Section 3001 of the Resource Conservation and Recovery Act (40 CFR 261.24), simulates the leaching an industrial waste would undergo when codisposed with municipal refuse in a non-secure landfill.

The simulation of the codisposal of municipal solid waste (MSW) with untreated industrial waste (IW) was initiated 28 October 1980. The 0.91 x 1.8 m cylindrical test cells were designed to simulate sanitary landfill environments. The 5 types of industrial waste were oil reclaiming clay, petroleum refinery incinerator ash, paint manufacturing sludge, solvent refining sludge, and tannery waste. Fifteen test cells were loaded providing triplicate samples of each IW leachate. All test cells have received an 8.4 liter (1.27 cm infiltrated rainfall) addition of deionized water each week. Leachate samples have been collected from the MSW and beneath the MSW-IW wastes on a monthly basis. Results of analyses for 7 inorganic parameters from leachate collected below the MSW and below MSW-IW are reported for 5 sample periods.

The increase in concentration of the metals in the below MSW-IW is compared to the change in concentration produced in the EP extract. When the published EP concentration criteria (100 time primary drinking water standards) for the specific metals was exceeded, the test cells also showed a concentration that exceeded the criteria. The EP concentrations are generally lower than the concentration of the same constituents from the same wastes in the test cells.

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The project was under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory, Mr. Andrew J. Green, Chief, Environmental Engineering Division, and Mr. Norman R. Francingues, Chief, Water Supply and Waste Treatment Group.

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SECTION I

INTRODUCTION

BACKGROUND

The Resource Conservation and Recovery Act of 1976 (RCRA) was enacted to provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials and for the safe disposal of discarded materials, and to regulate the disposal of hazardous waste. In the Act, a hazardous waste was defined as a solid waste which poses a substantial present or potential hazard to human health or the environment when improperly managed. Under Section 3001 of the Act, the Administrator of the Environmental Protection Agency (EPA) was charged with promulgating regulations identifying the characteristics of hazardous waste and listing of particular hazardous wastes.

Under this concept, two separate mechanisms were established for determining whether a waste is hazardous. The first mechanism involves the specific identification by source, or, in the case of discarded commercial chemical proudcts by chemical name of wastes that are considered to be hazardous in all waste management scenarios due to their toxic nature or potential for environmental harm. The specific wastes which have been identified and listed are generally those for which historical evidence of hazard exists. The second mechanism for determining whether a waste is hazardous is by a description of those properties which if possessed by a waste, may result in harm to either human health or the environment and thus may be hazardous. Under this second mechanism, a potential hazardous waste is evaluated using standard test procedures and the results compared to criteria established for various hazardous characteristics. EPA developed the following list of candidate characteristics:

1. Ignitability
2. Corrosivity
3. Reactivity
4. Extraction Procedure Toxicity
5. Radioactivity
6. Infectiousness
7. Phytotoxicity
8. Teratogenicity and Mutagenicity

To date, EPA has tended to rely only on consideration of the first four characteristics due to the absence of validated test protocols for the others and due in part to the fact that many radioactive wastes are separately regulated.

The definitions and associated test procedures for the first three characteristics are relatively straightforward and in general consistent with their historical meaning and use. EPA has given a somewhat limited connotation to the characteristic of toxicity than has historically been used due in part to a lack of a simple, well-accepted test or description to reliably identify all wastes exhibiting the various forms of toxicity. This study deals with the characteristic of Extraction Procedure Toxicity (EP). This characteristic has been developed, by EPA, as a means of identifying those wastes which pose a threat to ground water if placed in an insecure landfill especially in admixture with organic matter. As currently used by EPA, the term toxicity is related to the potential for a waste to present a chronic toxicity to humans based on the EPA National Interim Primary Drinking Water Standards as a result of the release of toxic constituents to the environment under conditions of improper management. This philosophy is based on the observation that wastes (primarily from industrial processes) have often been disposed of in sanitary landfills. These potentially hazardous wastes when disposed of with domestic refuse in a typical landfilling process would therefore be exposed to infiltrating precipitation and groundwater, and the acidic leachate normally generated by decomposing refuse. In this setting, the most likely pathway for contaminant migration and resulting environmental exposure is leaching to groundwater.

As a result, the EPA developed a test procedure to measure the potential of constituents of a waste material to migrate out of a landfill and contaminate the groundwater under poor management conditions. This procedure has been termed the Extraction Procedure (EP). The EP was designed to simulate the leaching action of the acidic leachate generated in municipal landfills, respectively. The EP as published in the regulations (40 CFR 261.24) involves the dilute acetic acid extraction of a sample of waste at a specified pH and with constant agitation over a period of 24 hours. The mixture is then filtered and the resulting extract is analyzed. Currently, the extract is analyzed for eight heavy metals (Ag, As, Ba, Cd, Cr, Se, Hg, Pb) and six organic compounds included on the list of National Interim Primary Drinking Water Standards (NIPDWS). Wastes generated an EP extract containing more than 100 times the concentration limits established for the NIPDWS are hazardous. The 100-times factor provides for dilution and attenuation of the contaminants as they migrate with introduction to the point of water use. The attenuation factor is applied in an effort to approximate concentration at the point of human exposure.

Considerable effort has been expended by the EPA in the development and selection of the EP. Numerous leaching tests were proposed and extensive laboratory evaluations were conducted prior to selection of the EP (1, 2, 3). No single test was found to fulfill all the requirements for simulating the natural leaching conditions associated with a landfill environment (3). After considerable debate, the EP was selected on the basis of its short test duration, simplicity, and relatively low cost which were very important considerations due to anticipated widespread use of the test.

A lack of consensus exists between EPA, the scientific community, and regulated industry on the validity of the EP test. Considerable debate continues on how well the EP simulates, predicts, or mimics the natural leaching

action in a municipal landfill environment. Concerns have been voiced that the EP does not address some of the factors thought to significantly affect leachate generation, including redox potential, buffer capacity, complexation capacity, ionic strength, surface area, and contact time. Time constraints did not permit EPA to conduct large-scale field verification testing of the EP prior to promulgation. Although large-scale industrial/municipal waste codisposal investigations have been reported in the literature (4, 5, 6, 7, 8), EP test results from the industrial wastes included in the investigations have, in general, not been available for comparison with the leachate analyses. In one investigation where comparative data were available, a preliminary analysis of the data indicated that the EP greatly overestimated the release of some constituents from the industrial wastes and underestimated the release of others (9).

As a result of the limited comparative data, EPA initiated a controlled study incorporating long-term, large-scale leaching tests of various industrial wastes in a simulated municipal solid waste landfill. Analyses of the leachates generated in the simulator could be compared with analyses conducted on the EP extracts to provide an evaluation of how well the EP simulates natural leaching in a landfill environment.

OBJECTIVES

The U. S. Army Engineer Waterways Experiment Station (WES) was tasked, through an interagency agreement with the EPA, to conduct a study directed toward obtaining comparative data from simulated landfill leaching and EP extraction of selected industrial wastes. The primary objective of this study was to determine how accurately the EP mimics landfill leaching of industrial waste. This objective was to be achieved by comparing the concentrations of selected potentially toxic constituents in the industrial waste EP extract with the increase in concentrations observed in the leachates from the test cells after contact with the industrial wastes. This comparison was aimed at verifying EPA's contention that the concentrations of potentially toxic constituents in the EP extracts should duplicate the highest concentrations (contributed by the industrial wastes) found in the leachates from the test cells.

A secondary objective of this study was to obtain data on the landfill leachability of selected organic compounds contained in some of the industrial wastes. This objective was to be achieved by selectively analyzing various leachate samples collected both before and after contact with the industrial wastes. EPA's goal is to develop a test that better simulates the natural leaching of potentially toxic organics in a landfill environment.

Due to the importance of the primary objective of this study with respect to the potential impact of the results on the perceived validity of the EP test currently in use, EPA took an active role in the design and conduct of the study. A peer-review group made up of members from various technical organizations provided technical input to the study and coordination between this study and other related studies being sponsored by EPA. Specific directions given and requests made by the group are noted throughout the study report.

This report provides a detailed discussion of the test program, presents the data obtained, and provides an interpretation and discussion of the results. Summary conclusions and recommendations for additional work are also presented. Discussion of the comparative results from the analyses conducted on the EP extracts and test cell leachates is limited to the metals included on the EP Toxicity contaminants list. Silver was excluded because it was not present in the wastes. Results of selected organic analyses of the test cell leachates are presented for informational purposes.

SECTION 2

CONCLUSIONS

This study highlighted several problems involved in the performance and interpretation of the Extraction Procedure Testing. Industrial wastes containing significant amounts of oil or other components that are not miscible with water present a mixing and filtering problem in the Extraction Procedure. It is difficult to insure complete mixing. The resulting lack of intimate contact between the waste solids and the EP leaching solution could limit the transfer of contaminants from the solids to the leaching solution. This problem was evident for the paint manufacturing sludge used in this study.

The metal concentrations in the EP extracts of wastes used in this study were generally low; many of the concentrations were below the detection limit of the analytical techniques employed. Only two wastes were found to have metal concentrations in the EP extracts above the maximum allowable concentrations. The EP extract from the petroleum refining incinerator ash had an average chromium concentration of 88.3 mg/l and the EP extract from the paint manufacturing sludge had an average lead concentration of 5.8 mg/l. As a result, these two wastes would be deemed as exhibiting the characteristic of EP toxicity.

With respect to the test cell leachates, the concentrations of arsenic, mercury, and selenium found were generally below detection limits. Concentration levels of the other metals in the test cell leachates varied depending on the industrial waste contained in the test cells. In general, the concentrations of the metals found at significant levels in the industrial waste leachates tended to decrease over the sampling periods.

The test cell leachates associated with four of the five industrial wastes had concentrations of metals in excess of ten percent of the EP thresholds allowable concentration for the EP toxicity metal contaminants. The solvent refining sludge leachate had none; the paint manufacturing sludge leachate had four metals (Cd, Cr, Hg, and Pb); the oil reclaiming clay leachate had two metals (Cr and Pb), and the petroleum refining incinerator ash and the tannery sludge leachates had one metal (Cr).

Two wastes were found to have metals concentrations in the test cell leachates above the EP thresholds. The leachates from the test cells containing the petroleum refining incinerator ash had an average chromium concentration of 136 mg/l. The leachate from the test cells containing the paint manufacturing sludge had an average lead concentration of 604 mg/l.

In the eight instances where metals concentrations in the industrial waste test cell leachates were more than ten percent of the EP thresholds, the metal concentrations in the industrial waste leachates generally ranged much higher (65 to 2000 times higher) than the concentrations found in the respective EP extracts. The only exceptions were the chromium concentrations associated with tannery sludge and the petroleum refining incinerator ash where the respective concentrations were more nearly comparable.

Of the metal concentrations found in the test cell leachates above the EP thresholds (chromium from the petroleum refining incinerator ash and lead from the paint manufacturing sludge), the concentrations of these same metals found in the respective EP extracts were also above the thresholds. On a qualitative basis, the EP correctly predicted the two industrial wastes in this study that would present a potential hazard with respect to releasing metal contaminants at concentrations above 100 times the primary drinking water standards.

The results of the limited organic analyses for toluene, xylene, and cresol in the municipal waste leachates and the industrial waste leachates indicated that the concentrations of the organics in the leachates collected before and after contact with the industrial wastes were very similar. It is evident that the toluene, xylene, and cresol, absent in the MSW, migrated as vapor from the industrial waste into the overlying municipal waste and were absorbed by the leachate. As a result, no net contribution of these organic contaminants from the industrial wastes could be quantified. However, the concentrations of the organics found in the leachates from three of the industrial wastes are sufficiently high to present a potential environmental hazard should they migrate into groundwater at a disposal site.

During conduct of the study, the municipal waste leachate samplers in the test cells as designed did not collect sufficient volumes of leachate for analysis. Based on observations made when the test cells were dismantled after completion of the study, this problem appears to have been the result of plugging of the samplers by partially deteriorated epoxy paint and to some extent by biological growth, and by diversion of leachate flow from the samplers due to large pieces of refuse, primarily paper, above and around the samplers.

Although the EP predicted qualitatively the two industrial wastes in this study that were shown in the test cells to release metal contaminants at concentrations above 100 times the primary drinking water standards, the EP in general grossly underestimated the highest concentrations found in the industrial waste test cell leachates. There is very little quantitative relation between the EP and test cell results.

SECTION 3

RECOMMENDATIONS

As a result of the problems encountered in this study in the collection of the municipal waste leachate, several modifications in test cell design should be considered if the test cells are to be used in further studies. These include replacing the perforated metal plates in the MSW samplers, to eliminate the need for the epoxy paint, and shredding of the municipal waste to reduce the size of individual pieces of paper or other material that could divert leachate flow. A more extensive redesign of the test cells would be required to eliminate the problems associated with migration of volatile organic contaminants into the refuse if quantification of net contribution of these contaminants from the industrial wastes is required. In this case, the municipal waste and the industrial waste should be physically separated, a design rejected by the EPA because of the required physical contact of MW and IW. The industrial wastes would be contained in separate sealed leaching cells. In this system, the municipal waste leachate would collect in the bottom of the test cells and then flow by gravity or be pumped to a second small cell containing the industrial waste to be leached. The municipal waste leachate from several cells could be combined to produce a more representative leachate before being used for industrial waste leaching. Correlations between EP and test cell results should be expanded to include additional industrial wastes types other than the five tested to allow a broader data base to be developed.

SECTION 4

MATERIALS AND METHODS

INDUSTRIAL WASTE

Representative hazardous industrial wastes for use in the study were selected by WES and approved by EPA on the basis of contaminant types and concentrations, and national industrial output volumes. All wastes were acquired from a commercial waste disposal facility in the upper mid-west. The facility manages large volumes of waste sludges from various industrial processors on a continuous basis thereby providing an immediate source for representative sludge from current operations. The selected industrial wastes represent the petroleum, paint manufacturing, solvent refining, and leather tanning industries. The wastes and respective waste producing processes are presented in Table 1. A 208-liter (55 gallon) drum of each of the five wastes was obtained via standard EPA methods and transported to WES.

Bulk Analyses

A bulk analysis was performed to establish base line data on a representative sample of each industrial waste obtained after the drum contents were thoroughly mixed. These analyses included metals, other inorganics, and some general organic parameters. As required for some analyses, total digests of

TABLE 1. INDUSTRIAL WASTES SELECTED FOR TESTING

Waste type	Generating process
Oil reclaiming clay	Filtration and cleanup of waste oil
Petroleum refining incinerator ash	Incineration of still and tank bottoms
Paint manufacturing sludge	Cleanup from paint mixing and pouring
Solvent refining sludge	Removal of still bottoms
Tannery sludge	Treatment of chrome tanning solutions

samples of the wastes were prepared. The digestion procedure was conducted using one gram of dried waste sample to which 0.5 ml of 30% hydrogen peroxide and 20 ml of 8N re-distilled nitric acid were added. The mixture was heated to dryness at 95°C or less and then redissolved in 25 ml of a solution containing 5% concentrated hydrochloric acid, 20% concentrated nitric acid, and 75% deionized water. This solution was then filtered in preparation for analysis. For those analyses not requiring an acid-digested sample, individual water samples were prepared as specified in Standard Methods (10) or Methods of Chemical Analysis of Water and Wastes (11). All bulk analyses were conducted in duplicate.

Extraction Procedure Testing

Samples of the industrial wastes were subjected to the EPA Extraction Procedure as described in the Code of Federal Regulations (40 CFR, Part 261, Appendix II). Separation of solid and liquid phases were accomplished using pressure filtration in a Millipore pressure filter (Model YT30 142 HW Millipore Corp., Bedford, MA 01730). Adjustment of pH was performed using the manual acid addition technique. An all-glass extraction vessel (Pyrex beakers with Phipps and Bird stirrers) with glass paddle stirrers was employed. All EP tests were conducted in triplicate.

MUNICIPAL WASTE

EPA personnel requested that municipal waste used in the study be obtained from a collection route generating only residential and commercial (non-industrial) waste thus reducing the potential for incorporation of significant amounts of industrial waste in the municipal waste. In response, waste collection routes in Vicksburg, MS were screened and routes containing only residences and small businesses were selected as source of municipal waste for the study. The municipal waste (approximately 8.5 metric tons) was collected from curbside locations and delivered to WES within 2 hours of collection.

TEST CELL DESIGN AND CONSTRUCTION

Study Requirements

The test cells were to be designed to contain industrial and municipal wastes in a simulated landfill situation. EPA specified that 5% (by weight) industrial waste and 95% municipal waste be used in the test cells to simulate actual emplacement ratios for codisposal operations. The industrial wastes be placed so as to be in direct contact with the overlying municipal waste. The ratio of wastes and emplacement method was to simulate expected landfill conditions for codisposal of industrial and municipal wastes. The municipal waste was to be compacted to a density of approximately 475 kg/m^3. Samples of leachate were to be collected from both above and below the industrial waste, or sludge, layer. The leachate sample collected above the industrial waste layer was representative of the leachate generated in the municipal waste and the sample collected from below the industrial waste layer was representative of the municipal waste leachate after it had been in contact with the industrial waste.

Test Cell Construction

The fifteen test cells were specifically designed and constructed to meet the requirement detailed above. Each test cell consisted of a cylindrical tank constructed of 0.64 cm thick steel supported by four angle iron legs approximately 75 cm long. Each tank was 208 cm high and 91 cm in diameter (Fig. 1) and was outfitted with three municipal waste leachate sampling ports and a single port in the bottom of the tank for sampling of leachate that had been in contact with both municipal and industrial waste.

Inside each tank, a false floor was placed near the bottom of the cylindrical section to provide a support for the municipal waste leachate collection devices, to serve as a platform for placement of the industrial waste and filter materials, and to provide a leachate reservoir in the bottom portion of the tank. The false floor (Fig. 2) consisted of a circular steel plate 1.27 cm thick with a diameter corresponding to the inside diameter of the tank. The floor was supported by flanges welded to the inner wall of the tank. Three 20.3 cm diameter steel leachate samplers were welded to the false floor so as to extend above the industrial waste and provide for collection of the municipal waste leachate. Between the three samplers, the false floor was perforated by 1.27 cm diameter holes to permit leachate drainage to the leachate reservoir below. Fiberglass screen was placed on the false floor around the three leachate collectors to prevent the filter sand and gravel from falling through the perforations into the reservoir below.

Each of the three municipal waste leachate samplers (Fig. 2) were constructed of steel pipe with a height of 25 cm (Fig 3). The samplers were of sufficient height so as to extend above the industrial waste layer into the municipal waste. Inside each sampler, 3.8 cm from the top, a circular perforated steel plate was inserted to provide a support for a gravel layer used to prevent the municipal waste from entering the samplers. A ring, 2.5 cm wide, was welded around the outside of each sampler to divert the flow of municipal waste leachate from the sides of the sampler and prevent channelized flow adjacent to the collector by deflecting leachate into MSW. A sample extraction port was installed in each sampler near the bottom. Teflon fittings and tubing was used to connect the ports in the samplers to the three municiapl waste leachate sampling ports located in the wall of each test cell.

A water distribution system was constructed for each test cell. The system consisted of a 89-cm diameter, plexiglass pan, three cm in depth with 1.6-mm holes drilled in the bottom on 2.5-cm centers. The pan was attached to the underside of the test cell cover. A graduated plastic carboy was placed on the top of each test cell for water storage. A Tygon tube inserted through a hole in the test cell cover was used to transfer the water from the carboy to the pan.

TEST CELL LOADING

The first steps in loading the test cells involved placement of the filter materials on the false floor and in the municipal waste leachate collectors. In each test cell, a 5.0 cm layer of quartz pea gravel was placed on the fiberglass screen covering the false floor. Pea gravel was also placed on

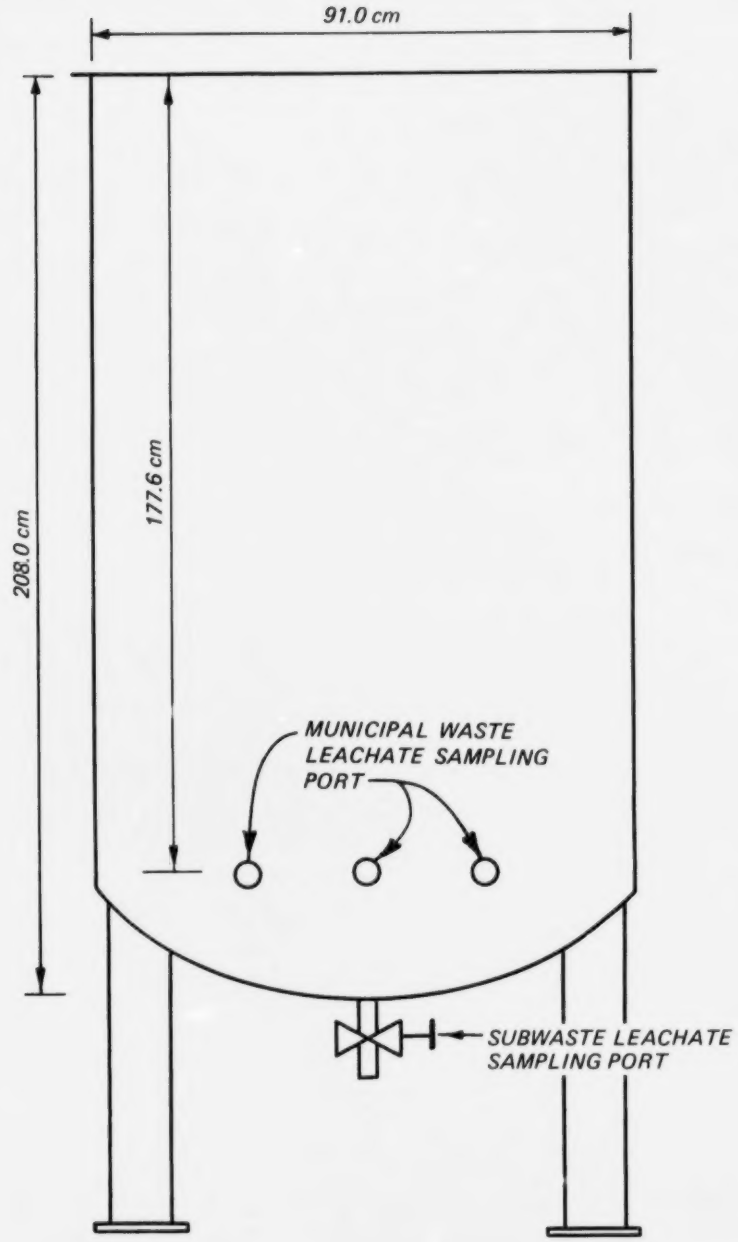

Figure 1. Exterior view of test cell showing positions of leachate sample collection ports.

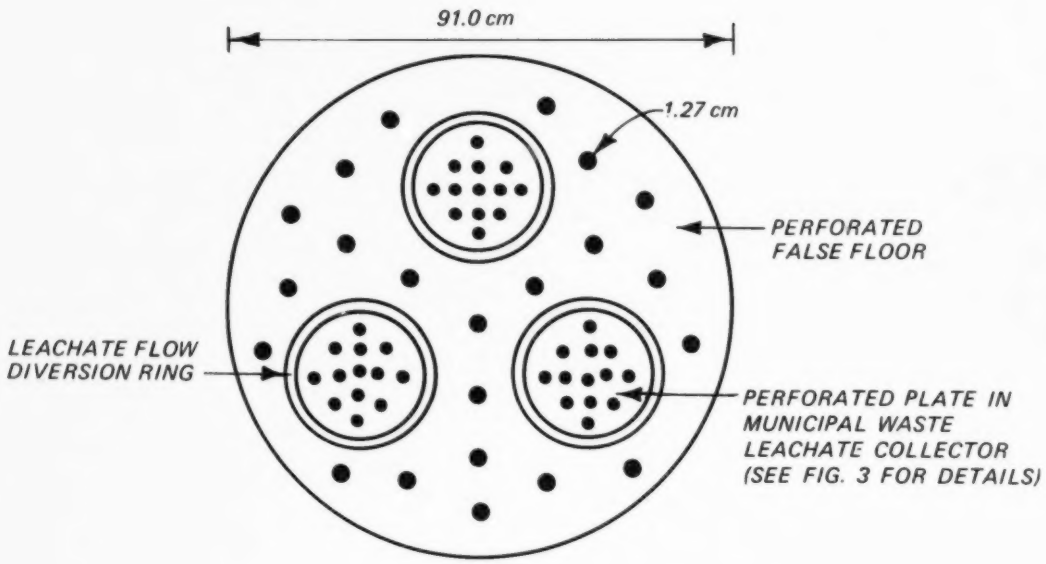
91.0 cm
1.27 cm
PERFORATED FALSE FLOOR
LEACHATE FLOW DIVERSION RING
PERFORATED PLATE IN MUNICIPAL WASTE LEACHATE COLLECTOR (SEE FIG. 3 FOR DETAILS)

Figure 2. Plan view of test cell showing perforated false floor with attached municipal waste leachate collectors.

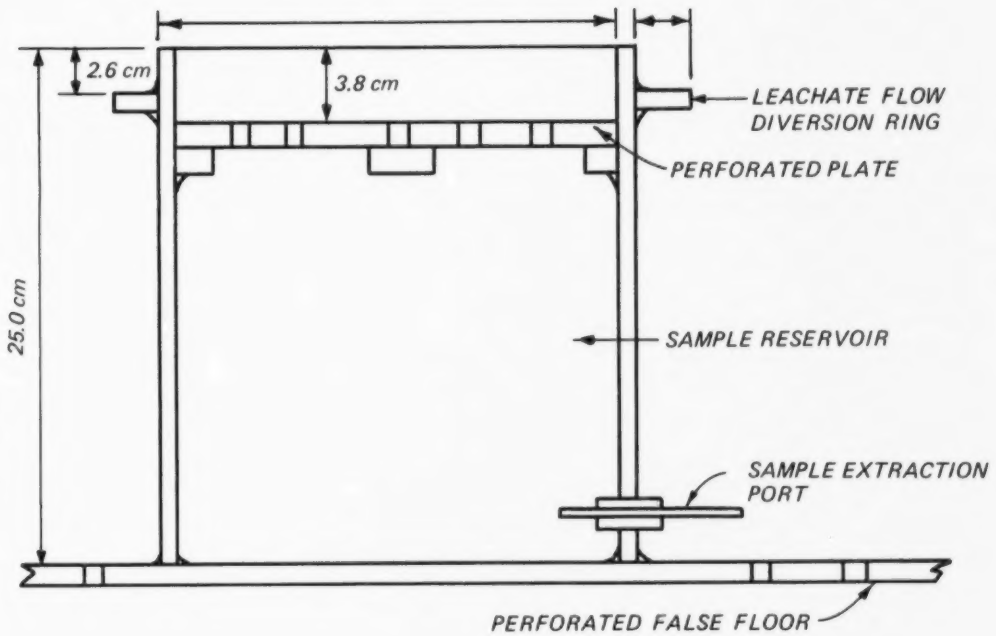

Figure 3. Cross-section of municipal waste leachate collector.

top of the perforated plate in each of the three leachate collectors. Next, a 7.5-cm layer of graded, quartz sand was placed over the pea gravel around the leachate collectors to provide a base for the industrial waste. Sand was not placed on top of the leachate collectors.

Next, the industrial wastes were loaded into the designated test cells and spread uniformly over the sand layers. Three test cells each received 15.9 kg of identical industrial waste resulting in a total of fifteen test cells for the five different industrial wastes. During loading of the industrial wastes, the municipal waste leachate collectors were covered to prevent contamination from any spillage of industrial waste. Care was also taken to insure that the walls of the test cells above the industrial waste layer were not contaminated by splashing or spillage of the industrial wastes during loading and spreading.

Upon arrival at WES, the municipal waste was discharged from the packer trucks into a mixing area. The mixing area consisted of a concrete slab with plywood walls and a removable plastic cover to prevent the introduction of dirt and precipitation into the waste. An excess amount of municipal waste was secured and mixed in order to provide homogeneous, representative subsamples for the test cells. Prior to and during mixing, large plastic sheets including garbage bags were emptied and removed from the waste to prevent their interference with the leachate samplers in the test cells. The waste was thoroughly mixed using a front-end loader. A preliminary compaction of the municipal waste was conducted in the mixing area using a bulldozer which tracked over the waste several times. This preliminary compaction resulted in the breaking of glass containers and the crushing of metal and plastic containers thus making compaction to the required density (540 kg/m^3) in the test cells easier.

Immediately following the loading of the industrial wastes, municipal waste was transported from the mixing area to the test cells in 208-l drums. The drums were loaded using a hopper system fed by a front-end loader. Each loaded drum was weighed and the tare weight of the drum subtracted to determined the weight of municipal waste contained. The municipal waste was placed in the test cells in successive lifts. After each lift was added, the waste was compacted with a hand tamp followed by a drop weight (230 kg.). Consistent density was achieved by compacting specific weight of waste to a corresponding volume. A total of 317.5 kg of municipal waste was placed in each test cell using five to seven separate lifts.

Loading of the test cells was completed by placing a 7.5 cm layer of quartz siliceous pea gravel on top of the compacted municipal waste. The purpose of this gravel layer was to prevent expansion of the municipal waste and to assure the uniform distribution of the water added across the top of each cell. The cell lids with the water distribution pans attached were then placed on top of the cells. A continuous bead of sealant was placed between the test cell wall and the lid to minimize evaporative losses from the test cells. Figure 4 presents a cross-section of a completed test cell. Loading of the fifteen test cells was completed in 26 hours, well within the 48 hour limit specified by EPA in project definition and scope.

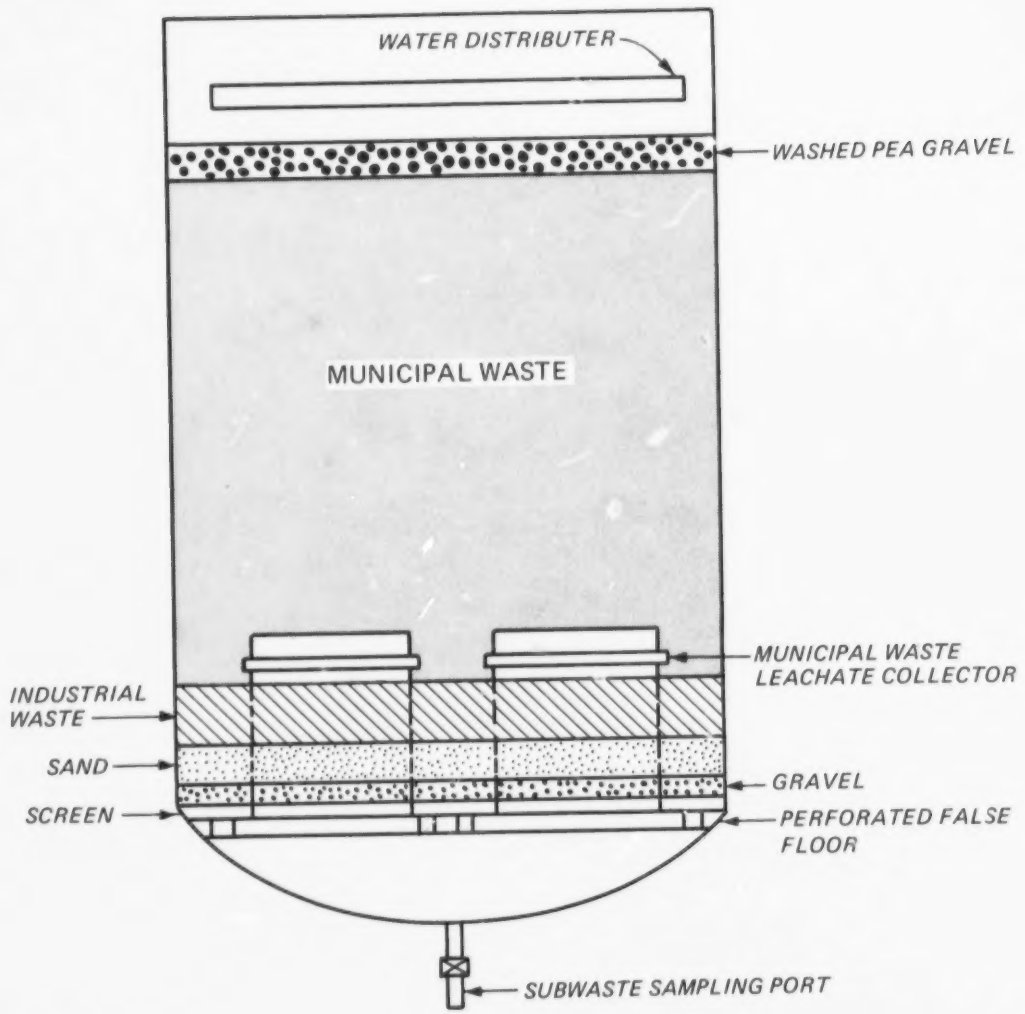

Figure 4. Cross-section of completed test cell.

TEST CELL OPERATION

Water Application

Immediately after all test cells were loaded (October 28, 1980), each cell received 8.4 liters of deionized water which is equivalent to 1.27 cm of infiltrated rainfall over the surface of the implaced waste. Thereafter, 8.4 liters of deionized water were applied to each test cell every seventh day until completion of the study. The MSW leachate collectors were continually monitored to detect the initial presence of leachate indicating field saturation of the municipal waste. Field saturation in all test cells was reached after a period of 137 days. An additional 54 days were required for sufficient leachate to accumulate in the municipal waste leachate collectors to provide the required volume for analysis.

Sample Collection, Preservation, and Processing

Leachate samples for analysis were collected from the test cells during five sampling periods. The starting date for the sampling periods are presented in Table 2.

TABLE 2. SAMPLING DATES FOR THE TEST CELLS

Sampling period	Date	Days from initial watering
1	May 6, 1981	191
2	June 11, 1981	227
3	July 13, 1981	259
4	August 18, 1981	295
5	October 21, 1981	359

Both the municipal waste leachate collectors and the collector in the bottom of each test cell were drained during each sampling period after samples were obtained for analysis. Thus, the samples were discrete for each sampling period. The total volumes of leachate removed during each sampling period, the total for all five sampling periods, and the amount of water added to each test cell prior to the sampling period are presented in Table 3. As noted in Table 3, there were losses of leachate from some of the test cells due to leaks which developed around the bulk-head fitting in the bottoms of the test cells. Upon discovery, the leaks were eliminated by application of additional epoxy sealant to the fittings.

All samples of leachate except those used for volatile organic analysis were drawn by suction from the test cells sampling ports through Tygon tubing

TABLE 3. TEST CELL LEACHATE COLLECTION AND WATER ADDITION VOLUMES

Waste type	Replicate test cell	Total water volume added and leachate volume collected					
		Sampling period 1 (ℓ)	Sampling period 2 (ℓ)	Sampling period 3 (ℓ)	Sampling period 4 (ℓ)	Sampling period 5 (ℓ)	Total (ℓ)
Water added to each test cell prior to sampling period		243.6	42.0	33.6	42.0	75.6	436.8
Oil reclaiming clay	A	138.5	46.2	32.9	55.6	94.5	367.7
	B	148.4	43.1	31.8	53.4	95.3	372.0
	C	134.7	41.6	26.9	53.7	94.9	351.8
Petroleum refining incinerator ash	A	133.2	44.3	31.4	54.5	11.3*	274.7
	B	146.5	43.9	33.3	51.5	17.0*	292.2
	C	148.0	17.0*	32.9	53.7	18.1*	269.7
Paint manufacturing sludge	A	129.1	42.4	31.0	54.5	56.1	313.1
	B	135.1	39.4	31.4	49.6	62.9	318.4
	C	140.8	40.1	30.7	53.7	98.7	364.0
Solvent refining sludge	A	9.1*	48.1	87.4	46.6	87.6	278.8
	B	169.2	42.0	32.6	47.3	21.1*	312.2
	C	140.8	43.1	33.7	56.0	12.0*	285.6
Tannery sludge	A	135.1	45.4	31.8	48.8	11.3*	272.4
	B	100.3	46.2	36.3	2.3*	48.5	233.6
	C	39.1*	28.8*	35.2	86.7	81.9	271.7

* Estimated volume loss due to leak in bottom of test cells.

into 500-ml, stoppered, glass aspirator bottles. The leachate was then transferred under pressure to a glovebox containing a helium atmosphere where subsamples were prepared. All lines were purged with helium prior to leachate sampling to maintain the leachate in an oxygen-free environment. In the glovebox, the subsamples collected for metals analysis (except mercury) were preserved by adding ultrapure nitric acid (to pH 2 or less). Subsamples for mercury analysis were collected separately in glass bottles without acidification, sealed, and transported to the analytical laboratory for immediate analysis. Samples for volatile organic analysis were collected directly from the leachate sampling ports into 40 ml glass vials and sealed using septums and screw-cap tops.

ANALYTICAL TECHNIQUES

A summary of the methods of analysis and lowest reporting concentrations for parameters reported are given in Table 4. The same methods of analysis were used for the bulk analysis, EP extracts, and leachates. A quality assurance program was established to ensure the reliability and comparability of the analytical data. National Bureau of Standards and EPA standard reference samples were used to verify all analytical techniques.

TABLE 4. METHODS OF ANALYSIS

Parameter	Procedures and/or instrumentation*	Lowest reporting concentration in aqueous solution (ppm)
As	Determined with a Perkin-Elmer Atomic Absorption Unit with Hydride System	0.01
Ba	Determined with a Spectrametrics Argon Plasma Emission Spectrophotometer Model II	0.01
Cd	Determined with a Perkin-Elmer Heated Graphite Atomizer Atomic Absorption Unit	0.0001
Cr	Determined with a Perkin-Elmer Heated Graphite Atomizer Atomic Absorption Unit	0.001
Hg	Determined by standard cold vapor technique on Perkin-Elmer Atomic Absorption Unit	0.0002
Pb	Determined with a Perkin-Elmer Heated Graphite Atomizer Atomic Absorption Unit	0.001
Se	Determined by standard gaseous hydride technique on Perkin-Elmer Atomic Absorption Unit	0.01
pH	Electrometric	--
Toluene	Determined using purge and trap (Tenak) method and a HP gas chromatograph	0.1
Xylene	Determined using purge and trap (Tenak) method and a HP gas chromatograph	0.1
Cresols	Determined using Base Neutral Acidic Extraction procedure and a HP gas chromatograph	0.1

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA procedures for priority pollutants, Federal Register, 3 Dec., 1979.

SECTION 5

RESULTS AND DISCUSSION

BULK ANALYSES

The complete results of the duplicate bulk analyses conducted on the five industrial wastes are presented in the Appendix. The average bulk concentrations of selected metals (from the EP Toxicity contaminants list, except silver) are presented in Table 5. The bulk analyses reflected the waste generating processes. A description of each waste type prior to leaching is given below.

Oil Reclaiming Clay

The oil reclaiming clay waste had the appearance of an oily solid. On the basis of the generation process, the waste should have been saturated with oil and contain adsorbed metals or metal particulates such as lead (originating from lead tetraethyl used as an "antiknock" additive in gasoline) and

TABLE 5. AVERAGE CONCENTRATIONS* FOR SELECTED METALS IN THE BULK ANALYSES OF INDUSTRIAL WASTES

Waste type	Metals						
	As	Ba	Cd	Cr	Hg	Pb	Se
Oil reclaiming clay	0.94†	191.	1.29	15.8	0.06	758.	0.35
Petroleum refining incinerator ash	33.2	136.	2.48	7400	<0.05	685.	8.80
Paint manufacturing sludge	<0.05	56,500	2.04	1830	28.3	46,400	0.50
Solvent refining sludge	<0.05	3,680	<0.05	<0.05	0.10	<0.50	0.20
Tannery sludge	0.21	139.	0.08	6370	0.11	18.7	0.50

* mg/kg, on a dry weight basis. Complete analyses and precent solids are given in Tables A-1 thorugh A-5.

† Values are the average of duplicate analyses.

other metals associated with used oil. This was verified by the bulk analyses. An average of 58 percent total solids was found for the waste. High concentrations for such parameters as oil and grease, total organic carbon (TOC), chemical oxygen demand (COD), and petroleum hydrocarbons indicate that the waste contained a significant amount of oil. Of the metals on the EP Toxicity contaminants list, lead was present in the highest concentration, 758 mg/kg.

Petroleum Refining Incinerator Ash

The incinerator ash waste was a dry free-flowing powder. This waste represents the residue remaining from the incineration of tank and still bottoms associated with oil refining. As a result of incineration, much of the organic material has been destroyed and most of the metals could be expected to be in the form of oxides or other salts with the metals in their highest normal oxidation states. The bulk analyses indicated some residual organics in the waste. Of the metals on the EP contaminants list, chromium and lead were found in high concentrations, averaging 7400 mg/kg and 685 mg/kg, respectively. In addition, iron and zinc were found in significantly high concentrations in the ash. These metals probably originated either from the crude oil, from catalysts used in the refining process, or fuel additives.

Paint Manufacturing Sludge

The paint manufacturing waste was generated from the cleanup of paint mixing and pouring lines and therefore consisted of waste paint and any cleaning solutions which may have been used. The waste was slightly off-white in color and could best be described as a viscous liquid containing some particulate material. The types of paint making up the waste are not definitely known. However, the paint waste did not mix well with water during the EP testing, suggesting the presence of some oil-based paint. The waste was found to contain approximately 40 percent total solids. The general organic parameters such as TOC and petroleum hydrocarbons were high. Of the metals on the EP contaminants list, barium and lead were found in very high concentrations, averaging 56,500 mg/kg and 46,400 mg/kg, respectively. An average chromium concentration of 1825 mg/kg was found. In addition to the EP metals, zinc was identified in high concentrations. These metals are characteristic of inorganic pigments widely used in the paint manufacturing industry. A mixture of barium sulfate and zinc sulfide (known as lithopone) is used as a white pigment. Basic lead carbonate (known as "white lead") is also used as a white pigment. Several chromium salts are used as pigments. Chromium oxide (with chromium in the trivalent state) is used as a green pigment (known as "chrome green"). Lead chromate and barium chromate (with chromium in the hexavalent state) are both used as yellow pigments.

Solvent Refining Sludge

The solvent refining waste was a dark gray, semi-solid material with a strong Xylene and Tolnene odor. The waste consisted of still bottoms from a solvent refining process. No information was available on the original uses of the solvents being refined. From the bulk analysis, the waste was found to contain approximately 37 percent total solids. As expected, the waste was

primarily organic with a TOC of approximately 80 percent. In general, the bulk analysis results indicated that the waste contained very low concentrations of the toxic metals with the exception of barium. The concentration of barium found was 3680 mg/kg. The source and chemical form of the barium in the waste are unknown.

Tannery Sludge

The tannery waste consisted of the sludge generated from the treatment of a chrome tanning solution. The waste was a somewhat viscous liquid with clumps of solids and a greenish tint. The waste emitted a putrid odor with a perceptible hydrogen sulfide content. Although the exact treatment process that generated the waste sludge is unknown, a typical tannery waste process generally includes coagulation and sedimentation using ferrous sulphate with lime, or other similar coagulants. In this type of treatment process, the colloidal albuminous substances are coagulated and chromium is precipitated as chromic hydroxide. As a result of the strongly reduced state of the waste, the metals contained in the waste (particularly iron and chromium) should be present in their lowest normal oxidation state. From the bulk analysis, the waste was found to contain only about 9 percent total solids. Some oil, grease, and petroleum hydrocarbons were found. The high COD value found is indicative of the highly reduced state of the waste. As expected under the existing anaerobic conditions, a high concentration of ammonia was found. The high concentrations of calcium and iron indicate that salts of these metals were used in the treatment process. Of the metals on the EP contaminants list, only chromium was found in high concentrations, averaging 6370 mg/kg.

EP EXTRACT ANALYSES

Table 6 presents the average metals concentrations found in the EP extracts of the industrial wastes for the metals included on the EP contaminants list (except silver) along with the maximum allowable concentrations. These concentrations are the averages of three values obtained from the analyses conducted on three separate EP extracts from each waste. For the purpose of averaging, concentrations that were less than the lowest reportable value were set equal to that less than value. The reproducibility of the results was very good. In many cases, the concentrations found in the replicate extracts for a particular metal were all within ten percent of the mean value.

In general, the metals concentrations in the EP extracts were very low; many of the concentrations were below the lowest reporting value. Only two wastes were found to have metals concentrations above the maximum allowable concentrations. The EP extract from the petroleum refining incinerator ash had an average chromium concentration of 88.3 mg/l and the EP extract from the paint manufacturing sludge had an average lead concentration of 5.83 mg/l. The maximum allowable concentration for both these metals is 5.0 mg/l. As a result, these two wastes would be considered hazardous, by the toxicity characteristics under the RCRA regulations. The only other waste extract having a metal concentration approaching the maximum allowable value was the tannery sludge extract with an average chromium concentration of 2.2 mg/l.

TABLE 6. AVERAGE METALS CONCENTRATIONS FOUND IN EP EXTRACTS OF THE INDUSTRIAL WASTES COMPARED TO THE MAXIMUM ALLOWABLE CONCENTRATIONS

Waste type	Metals						
	As	Ba	Cd	Cr	Hg	Pb	Se
Oil reclaiming clay	0.01*	0.01	0.0001	0.001	0.0002	0.002	0.01
Petroleum refining incinerator ash	0.08	0.11	0.0020	88.3	0.0002	0.009	0.02
Paint manufacturing sludge	0.01	0.02	0.0051	0.001	0.0002	5.83	0.01
Solvent refining sludge	0.01	0.01	0.0002	0.009	0.0002	0.002	0.01
Tannery sludge	0.01	0.14	0.0003	2.20	0.0002	0.001	0.01
Maximum allowable concentration with respect to EP toxicity+	5.0	100	1.0	5.0	0.2	5.0	1.0

* Values are the average of triplicate analyses and are expressed as mg/L.

\+ Reference: 40 CFR, Part 261, Section 261.24.

** For the purpose of averages "less than" values are assumed to be their absolute values.

Several interesting observations were made during the EP testing of the wastes and from a comparison of the bulk and extract analytical results. As previously mentioned, the paint manufacturing sludge did not mix well with the water/acetic acid solution during EP testing. The paint tended to float on the water in the beaker and was not miscible. Also, the paint tended to adhere to all surfaces with which it came in contact including the walls of the beaker, the stirrer, the pH probe, and the filtering equipment. This made filtering of the paint waste very difficult. As a result of these problems, the lack of complete mixing and the resulting lack of intimate contact between the waste solids and the EP leaching solution probably limited the transfer of contaminants from the solid material to the leaching solution. Therefore, the concentrations of the contaminants found in the EP extract from the paint waste may be low. This is hard to verify with respect to the metal contaminants identified in high concentrations in the bulk analysis, namely barium and lead, because of the very low solubilities of the chemical forms in which these metals probably exist in the waste.

The importance of the oxidation state of a metal with respect to solubility was apparent during this study. Similar bulk chromium concentrations were found in the petroleum refining incinerator ash and the tannery sludge; however, the chromium concentrations found in the EP extracts of these two wastes were quite different. The concentration of chromium in the extract from the

incinerator ash was forty times that found in the extract from the tannery sludge. Based on the information available on the generation of these two wastes, most of the chromium contained in the incinerator ash was probably in the hexavalent state while most of the chromium in the tannery sludge was probably in the trivalent state.

The comparison of the EP analytical results and the bulk concentrations of the metal contaminants in the wastes indicate that bulk analyses do not necessarily provide an indication of the hazard potential of a waste with respect to leaching and migration as defined by the EP. Very high concentrations of metals in the wastes in this study did not produce corresponding, high concentrations in the EP extracts. Similar concentrations of the same metal in different wastes did not produce corresponding, similar concentrations in the EP extracts of the wastes. As discussed, this absence of correlation for the specific metals can be due, in part, to variations in the chemical form or oxidation state in which the metal contaminant exists in a particular sludge. If the EP accurately mimics landfill leaching of contaminants from such an industrial waste, then the lack of correlation is not particularly important. However, if the EP does not provide a good prediction of the leaching potential of the contaminants, the lack of correlation becomes important especially in those cases where high concentrations of contaminants are identified in the bulk analyses but are not reflected in the results obtained from the EP.

TEST CELL LEACHATE ANALYSES

The results of the metals analyses and pH determinations conducted on the test cell leachates collected during the five sampling periods are presented in Tables 7-11. The results of the selected organics (toluene, xylene, and cresol) analyses of leachates collected from test cells associated with three industrial wastes (paint manufacturing, solvent refining and tannery operation wastes) over four sampling periods are presented in Tables 12-14. Each table presents the individual results of the analyses conducted on the municipal waste leachates (collected above the industrial waste layer) and the industrial waste leachates (collected from the bottom of each test cell) collected from the three replicate test cells containing a particular industrial waste. As indicated in the tables, analyses were not conducted on the municipal waste leachates during each sampling period (as originally planned) due to insufficient volume for analysis.

Summary of Metals Analyses and pH

As indicated in Tables 7-11, the concentrations of arsenic, mercury, and selenium found in the leachates were generally low; no concentrations of selenium above the lowest reportable value, were found. The pH of the leachates did not vary significantly over the five sampling periods.

Concentrations of mercury significantly above the lowest reportable value were found only in the industrial waste leachates from the test cells containing the paint manufacturing sludge. Concentration levels of the other metals found in the industrial waste leachates varied depending on the industrial waste contained in the test cells. In general, the concentrations of the

TABLE 7. METAL AND pH ANALYSES OF LEACHATE FROM TEST CELLS CONTAINING OIL RECLAIMING CLAY

Replicate test cell	Leachate collection point	Sampling periods	pH	Metals[1]						
				As	Ba	Cd	Cr	Hg	Pb	Se
A	Above IW layer*	1	N‡	0.05	1.91	0.0063	0.610	<0.0002	0.434	<0.01
	Below IW layer+	1	5.2	0.02	0.51	0.0036	0.690	<0.0002	0.253	<0.01
		2	5.1	0.04	0.32	0.0036	2.08	<0.0002	0.420	<0.01
		3	5.2	0.02	N	0.0016	0.592	<0.0002	0.202	<0.01
		4	6.1	0.02	N	0.0016	0.440	<0.0002	0.110	<0.01
		5	5.3	0.02	N	0.0060	0.295	<0.0002	0.043	<0.01
B	Below IW layer	1	5.8	0.01	0.20	0.0024	0.143	<0.0002	4.34	<0.01
		2	5.2	0.02	0.06	0.0059	0.168	<0.0002	0.197	<0.01
		3	5.3	0.01	N	0.0007	0.093	<0.0002	0.359	<0.01
		4	6.2	0.01	N	0.0003	0.109	<0.0002	0.251	<0.01
		5	5.1	0.02	N	0.0023	0.120	<0.0002	0.008	<0.01
C	Below IW layer	1	5.8	0.02	0.18	0.0053	7.44	<0.0002	0.019	<0.01
		2	5.6	0.01	0.11	0.0020	1.59	<0.0002	0.300	<0.01
		3	5.1	0.01	N	0.0022	1.06	<0.0002	0.131	<0.01
		4	6.0	0.03	N	0.0051	0.834	<0.0002	0.193	<0.01
		5	5.4	0.03	N	0.0048	0.600	<0.0002	0.110	<0.01

1 Expressed in mg/ℓ.

* Indicates muncipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

‡ Analysis not done.

TABLE 8. METAL AND pH ANALYSES OF LEACHATE FROM TEST CELLS CONTAINING PETROLEUM REFINING INCINERATOR ASH

Replicate test cell	Leachate collection point	Sampling periods	pH	Metals[1]						
				As	Ba	Cd	Cr	Hg	Pb	Se
A	Above IW layer*	1	N‡	<0.01	0.27	0.0005	0.301	<0.0002	0.033	<0.01
	Below IW layer+	1	6.3	0.01	0.06	0.0130	144.	0.0005	0.055	<0.01
		2	5.4	0.01	0.05	0.0024	44.0	<0.0002	0.591	<0.01
		3	5.7	0.01	N	0.0012	19.9	<0.0002	0.020	<0.01
		4	6.8	0.02	N	0.0088	7.31	<0.0002	0.253	<0.01
		5	7.0	0.12	N	0.0053	13.3	<0.0002	0.229	<0.01
B	Above IW layer	1	N	0.02	1.15	0.0012	10.9	<0.0002	0.026	<0.01
		2	N	0.14	1.32	0.0033	0.192	<0.00^2	5.48	<0.01
		5	N	0.08	N	0.0057	0.180	0.0011	5.42	<0.01
	Below IW layer	1	6.0	<0.01	0.09	0.0027	76.8	<0.0002	0.021	<0.01
		2	5.4	0.01	0.12	0.0006	21.3	N	0.180	<0.01
		3	5.5	0.01	N	<0.0001	4.86	<0.0002	0.050	<0.01
		4	6.5	0.02	N	<0.0001	3.53	<0.0002	0.042	<0.01
		5	6.4	0.15	N	0.0035	1.76	<0.0002	0.189	<0.01
C	Below IW layer	1	6.0	0.02	0.14	0.0008	205.	<0.0002	0.220	<0.01
		2	5.8	<0.01	0.11	0.0008	26.2	<0.0002	0.720	<0.01
		3	5.3	<0.01	N	<0.0001	6.07	<0.0002	0.171	<0.01
		4	6.3	0.01	N	0.0012	3.45	<0.0002	0.681	<0.01
		5	6.8	0.02	N	0.0027	2.39	<0.0002	0.132	<0.01

1 Expressed in mg/ℓ.

* Indicates muncipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

‡ Analysis not done.

TABLE 9. METAL AND pH ANALYSES OF LEACHATE FROM TEST CELLS CONTAINING PAINT MANUFACTURING SLUDGE

Replicate test cell	Leachate collection point	Sampling periods	pH	Metals[1]						
				As	Ba	Cd	Cr	Hg	Pb	Se
A	Below IW layer*	1	5.2	0.01	1.23	0.350	1.72	0.0640	672.	<0.01
		2	5.0	0.01	0.35	0.132	1.31	0.0350	351.	<0.01
		3	5.3	0.01	N‡	0.0680	0.662	0.0195	258.	<0.01
		4	6.2	0.02	N	0.0426	0.296	0.0002	96.2	<0.01
		5	5.3	0.01	N	0.0203	0.145	0.0130	61.6	<0.01
B	Below IW layer	1	5.6	<0.01	0.73	0.364	1.18	0.0540	750.	<0.01
		2	5.6	<0.01	0.31	0.101	0.296	0.0475	433.	<0.01
		3	5.1	<0.01	N	0.0723	0.315	0.0270	298.	<0.01
		4	6.2	<0.01	N	0.0675	0.197	0.0180	281.	<0.01
		5	5.1	0.01	N	0.0424	0.151	0.0120	73.5	<0.01
C	Above IW layer+	1	5.3	0.02	1.87	0.0083	0.143	0.0020	13.1	<0.01
		2	N	0.03	0.85	0.0057	0.097	0.0022	18.2	<0.01
		3	5.1	0.03	N	0.0025	0.069	0.0010	0.140	<0.01
		4	N	0.04	N	0.0022	0.071	0.0006	0.341	<0.01
		5	N	0.07	N	0.0035	0.064	0.0002	0.182	<0.01
	Below IW layer	1	5.0	<0.01	0.74	0.293	0.677	0.0025	428.	<0.01
		2	5.6	<0.01	0.21	0.104	0.244	0.130	186.	<0.01
		3	5.1	0.01	N	0.0700	0.183	0.0120	215.	<0.01
		4	6.0	0.02	N	0.0390	0.136	0.0110	96.0	<0.01
		5	5.1	0.03	N	0.0231	0.108	0.0010	53.6	<0.01

1 Expressed in mg/ℓ.

* Indicates leachate collected from the bottom of the test cell.

\+ Indicates muncipal waste leachate.

‡ Analysis not done.

TABLE 10. METAL AND pH ANALYSES OF LEACHATE FROM TEST CELLS CONTAINING SOLVENT REFINING SLUDGE

Replicate test cell	Leachate collection point	Sampling periods	pH	Metals[1]						
				As	Ba	Cd	Cr	Hg	Pb	Se
A	Above IW layer*	1	5.2	0.03	0.34	0.0026	0.081	<0.0002	0.032	<0.01
		2	5.0	0.03	0.18	0.0007	0.120	<0.0002	0.062	<0.01
		3	5.2	0.03	N‡	0.0005	0.095	<0.0002	0.083	<0.01
		4	6.1	0.07	N	0.0001	0.118	<0.0002	0.122	<0.01
	Below IW layer+	1	5.3	0.02	0.07	0.0440	0.208	<0.0002	0.150	<0.01
		2	5.2	0.02	0.04	0.0086	0.177	<0.0002	0.122	<0.01
		3	5.5	0.01	N	0.0083	0.134	<0.0002	0.126	<0.01
		4	6.1	0.01	N	0.0016	0.129	<0.0002	0.085	<0.01
		5	5.2	0.02	N	0.0026	0.110	<0.0002	0.053	<0.01
B	Below IW layer	1	6.0	<0.01	0.18	0.0350	0.408	<0.0002	0.310	<0.01
		2	5.7	0.01	0.04	0.0047	0.261	<0.0002	0.117	<0.01
		3	5.2	<0.01	N	0.0021	0.237	<0.0002	0.066	<0.01
		4	6.1	0.01	N	0.0022	0.151	<0.0002	0.147	<0.01
		5	5.0	0.01	N	0.0036	0.146	<0.0002	0.032	<0.01
C	Below IW layer	1	5.8	0.02	0.12	0.0110	0.229	<0.0002	0.199	<0.01
		2	5.7	0.01	0.09	0.0042	0.160	<0.0002	0.129	<0.01
		3	5.3	0.01	N	0.0037	0.175	<0.0002	0.180	<0.01
		4	6.0	0.03	N	0.0030	0.126	<0.0002	0.172	<0.01
		5	5.2	0.03	N	0.0037	0.117	<0.0002	0.127	<0.01

1 Expressed in mg/ℓ.

* Indicates muncipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

‡ Analysis not done.

TABLE 11. METAL AND pH ANALYSES OF LEACHATE FROM TEST CELLS CONTAINING TANNERY SLUDGE

Replicate test cell	Leachate collection point	Sampling periods	pH	Metals[1]						
				As	Ba	Cd	Cr	Hg	Pb	Se
A	Above IW layer*	1	N‡	0.04	1.08	0.0004	0.119	<0.0002	0.012	<0.01
		2	N	0.10	1.09	0.0019	0.131	<0.0002	0.213	<0.01
		3	N	0.03	N	0.0004	0.020	<0.0002	0.110	<0.01
	Below IW layer+	1	5.3	0.02	0.53	0.0002	1.01	<0.0002	0.056	<0.01
		2	5.4	0.03	0.33	0.0002	0.168	<0.0002	0.025	<0.01
		3	5.6	0.01	N	0.0001	0.347	<0.0002	0.025	<0.01
		4	7.5	0.01	N	0.0007	0.223	<0.0002	0.053	<0.01
		5	6.7	0.02	N	0.0021	0.145	<0.0002	0.026	<0.01
B	Above IW layer	1	5.4	0.16	1.99	0.0004	0.175	<0.0008	0.013	<0.01
		2	N	0.07	0.80	0.0004	0.101	<0.0002	0.031	<0.01
		4	N	0.07	N	0.0011	0.115	<0.0002	0.118	<0.01
	Below IW layer	1	5.4	0.06	0.73	0.0011	0.434	<0.0006	0.131	<0.01
		2	5.7	0.03	0.39	0.0028	0.228	<0.0002	0.063	<0.01
		3	5.4	0.02	N	0.0012	0.181	<0.0002	0.051	<0.01
		4	6.3	0.02	N	<0.0001	0.163	<0.0002	0.060	<0.01
		5	5.8	0.02	N	0.0022	0.126	<0.0002	0.014	<0.01
C	Above IW layer	2	N	0.01	1.14	0.0019	0.273	<0.0002	0.019	<0.01
	Below IW layer	1	5.5	<0.01	0.58	0.0002	0.562	<0.0002	0.041	<0.01
		2	5.9	<0.01	0.50	0.0006	0.599	<0.0002	0.017	<0.01
		3	5.5	0.10	N	0.0003	0.473	<0.0002	0.034	<0.01
		4	6.4	0.02	N	0.0008	0.385	<0.0002	0.029	<0.01
		5	5.5	0.02	N	0.0031	0.320	<0.0002	0.196	<0.01

1 Expressed in mg/ℓ.

* Indicates muncipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

‡ Analysis not done.

TABLE 12. CONCENTRATIONS OF SELECTED ORGANICS IN LEACHATE FROM TEST CELLS CONTAINING PAINT MANUFACTURING SLUDGE

Replicate test cell	Leachate collection point	Sampling period	Organics†		
			Toluene	Meta and Para Xylene	Ortho Xylene
A	Below IW layer*	1	59.0	26.2	6.70
		2	62.6	35.4	9.04
		4	42.9	27.2	7.88
B	Below IW layer	1	54.2	27.8	8.45
		2	44.4	39.6	8.90
		4	25.6	23.2	7.78
C	Above IW layer+	1	64.5	27.5	8.65
		2	55.3	31.7	9.90
		4	47.8	29.7	8.60
	Below IW layer	1	68.8	24.8	5.10
		2	73.8	31.6	2.20
		4	44.3	24.7	7.38

* Indicates leachate collected from the bottom of the test cell.

\+ Indicates municipal waste leachate.

† Expressed in mg/ℓ.

TABLE 13. CONCENTRATIONS OF SELECTED ORGANICS IN LEACHATE FROM TEST CELLS CONTAINING SOLVENT REFINING SLUDGE

Replicate test cell	Leachate collection point	Sampling period	Organics†		
			Toluene	Meta and Para Xylene	Ortho Xylene
A	Above IW layer*	1	4.70	33.4	11.0
		2	3.44	57.8	15.5
		4	3.40	26.3	11.4
	Below IW layer+	1	1.71	17.8	6.00
		2	4.34	39.6	14.0
		4	3.16	28.9	13.0
B	Below IW layer	1	3.60	31.7	12.8
		2	3.74	52.1	16.0
		4	3.16	33.0	14.2
C	Below IW layer+	1	3.26	23.0	15.9
		2	2.98	48.4	3.42
		4	2.80	33.4	14.5

* Indicates municipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

† Expressed in mg/ℓ.

TABLE 14. CONCENTRATIONS OF SELECTED ORGANICS IN LEACHATE FROM TEST CELLS CONTAINING TANNERY SLUDGE

Replicate test cell	Leachate collection point	Sampling period	Ortho Cresol (mg/ℓ)	Meta and Para Cresol (mg/ℓ)
A	Above IW layer*	1	14.2	46.4
		2	11.5	35.9
		3	8.70	39.3
	Below IW layer+	1	3.40	54.4
		2	3.90	51.9
		3	3.50	49.3
B	Above IW layer	1	7.40	43.9
		2	8.00	31.3
		3	11.3	35.6
	Below IW layer	1	3.60	40.3
		2	4.10	56.8
		3	3.10	46.0
C	Above IW layer	2	9.80	40.1
	Below IW layer	1	3.55	50.0
		2	5.10	72.1
		3	4.80	64.7

* Indicates municipal waste leachate.

\+ Indicates leachate collected from the bottom of the test cell.

metals found at significant levels in the industrial waste leachates tended to decrease over the sampling periods. That is, the highest concentrations found were generally associated with the industrial waste leachate collected during the first sampling period.

Some of the metals concentrations in the municipal waste leachates varied considerably between test cells. It is thought that this resulted in part from the inability of the municipal waste leachate samplers to collect a sufficient portion of the total leachate flow as designed. Because of the small volumes of leachate collected, even a small contribution of a contaminant from an isolated source in the municipal waste located above one of the samplers could result in a significant concentration of the contaminant being found in the leachate. This would depend on the volume of leachate collected prior to sampling and on the relative volume of leachate collected by each of the three samplers. Even though the municipal waste was thoroughly mixed prior to

placement in the test cells, the waste cannot be considered totally homogeneous due to the great variety of materials included and the size of individual pieces of refuse in the waste with respect to the size of the test cells and, in particular, the size of the samplers.

In order to evaluate the leachate concentrations found with respect to the EP contaminant concentration criteria, and in keeping with EPA's contention that the EP results should duplicate the highest concentrations found in the leachates from the test cells, a summary of the analytical results from the leachate analyses was undertaken to provide for clarity and ease in evaluation and comparison of results. The first step in summarizing the data was to average the three highest concentrations found in the leachates for a particular metal from the replicate test cells associated with each industrial waste. The concentrations found in the municipal waste leachates and the industrial waste leachates were both averaged separately so that the concentration in the municipal waste leachate could be subtracted as "background" from the concentration in the industrial waste leachate. In those cases where there were no municipal waste leachate analytical results for a test cell or for a sampling period due to a lack of sufficient sample, the results for the nearest sampling period from a replicate test cell containing the same industrial waste were used. Subtraction of the municipal waste leachate metals concentrations from the industrial waste leachate metals concentrations resulted in a number of concentration values at or even below the lowest reportable value for a particular metal. The negative values found indicated that either the portion of the municipal waste leachate collected in the samplers was not representative of the total volume of municipal waste leachate generated or that the industrial wastes were adsorbing or otherwise retaining some of the metals.

In any case, the low concentrations found for many of the metals indicated that these contaminants were not being leached from their associated industrial wastes in concentrations that would represent a hazard to the environment. It was therefore decided to delete these metals from further evaluation with respect to the individual industrial wastes and comparison with the EP results. It was deemed inappropriate to compare the analytical results from the test cell leachates and the EP extracts at concentrations near the lowest reportable value. At this level variations in analytical values are most likely to be significant and where values are unimportant with respect to hazard potential under the RCRA regulations in specific cases. A lower limit of ten percent of the maximum allowable concentration for the EP toxicity metal contaminants was selected for use in deleting metals associated with particular industrial wastes from further evaluation. This level was high enough to eliminate those metals for which the concentrations found in the industrial waste leachates were significantly effected by subtraction of the concentrations from the municipal waste leachates. This eliminated the importance that any anomalies in the analytical results in the municipal waste leachates might have on the evaluation of the data due to limited number of analyses obtained on the municipal waste leachates. Although no regulatory guidance exists, it was decided that the EP results should be expected to be comparable to the results on the test cell leachates down to the ten percent level.

Table 15 presents the highest average concentrations of the metals in the leachates for each industrial waste in which the concentrations found were above the ten percent cut-off level. In addition, the range of concentrations included in the average value are given along with the average concentration found in the associated municipal waste leachate. The last column in Table 15 presents the highest average concentrations of metals found in the industrial waste leachates from which the concentrations in the municipal waste leachates (background) have been subtracted. These concentrations represent the net contributions of metal contaminants by the industrial wastes and are the values that will be compared to the EP results.

As indicated in Table 15, the test cell leachates associated with only four of the five industrial wastes had concentrations of metals above the ten percent cut-off level. The solvent refining sludge was eliminated on the basis of the evaluation described above. The paint manufacturing sludge produced concentrations of four metals above the cut-off level (Cd, Cr, Hg, and Pb) while the oil reclaiming clay produced two (Cr and Pb) and the petroleum refining incinerator ash and the tannery sludge produced one each (Cr). All four wastes produced concentrations of chromium above the cut-off level. The range in concentrations for some of the metals was appreciable indicating a lack of reproducibility of leaching conditions between the associated replicate test cells. The results obtained from the test cells containing the paint manufacturing sludge indicate that the lack of reproducibility for some metals is probably not a result of the test procedures employed since the range in concentrations found varies between different metals.

The highest average concentrations of the metals corrected for background were compared to the maximum allowable concentrations for the metals on the EP toxicity contaminants list. Only two wastes were found to have metals concentrations above the maximum allowable concentrations. The leachates from the test cells containing the petroleum refining incinerator ash had a highest average chromium concentration of 136 mg/l. The leachate from the test cells containing the paint manufacturing sludge had a highest average lead concentration of 604 mg/l. The maximum allowable concentration for both these metals is 5.0 mg/l.

Some of the same observations noted as a result of comparing the bulk and EP extract analytical results were made upon comparing the bulk and test cell leachate analytical results. The chemical form or oxidation state in which the metal contaminant exists in the waste is very important with respect to its leaching potential and therefore the potential hazard it presents to the environment. A comparison of the concentrations found for barium and lead in the bulk samples and test cell leachates for the paint manufacturing sludge provides a good example of the difference in hazard potential. Bulk concentrations for barium and lead in the paint sludge were 56,500 mg/l and 46,400 mg/l, respectively. The highest average barium concentration in the test cell leachates was 0.9 mg/l before background correction with the background concentration being slightly higher. Therefore, the paint sludge contributed essentially no barium to the industrial waste leachate and thus the barium does not represent a potential hazard with respect to migration. The highest average lead concentration contributed by the paint sludge was 604 mg/l which represents a definite migration hazard to the environment.

TABLE 15. HIGHEST AVERAGE CONCENTRATIONS[+] FOR METALS IN THE TEST CELL INDUSTRIAL WASTE LEACHATES ABOVE TEN PERCENT OF THE MAXIMUM ALLOWABLE CONCENTRATIONS FOR THE EP TOXICITY METAL CONTAMINANTS

Waste type and metal contaminant	Highest Average concentration	Range of concentrations		Average concentration in municipal waste leachate	Highest Average concentration minus background*
		Lowest	Highest		
Oil reclaiming clay					
Cr	3.23	0.168	7.44	0.610	2.62
Pb	1.69	0.300	4.34	0.434	1.26
Petroleum refining incinerator ash					
Cr	141.6	76.8	205.	5.60	136.
Paint manufacturing sludge					
Cd	0.336	0.293	0.364	0.0083	0.328
Cr	1.19	0.677	1.72	0.143	1.05
Hg	0.0437	0.0130	0.0640	0.0021	0.0416
Pb	617.1	428.	750.	13.1	604.
Tannery sludge					
Cr	0.681	0.434	1.01	0.160	0.521

* Represents the contribution of metal contaminants by the industrial wastes.

\+ Expressed in mg/ℓ.

These examples again illustrate that bulk analyses do not necessarily provide an indication of the hazard potential of a waste with respect to leaching and migration as defined by the EP.

Summary of Selected Organics Analyses

As previously discussed, a secondary objective of this study was to obtain data on the landfill leachability of selected organic compounds contained in some of the industrial wastes. A preliminary qualitative screening of the industrial wastes was conducted using standard GC/MS techniques to identify organics contained in high concentrations in the sludges that could be analyzed for in the test cell leachates. None of the organics on the EP toxicity contaminants list were found in significant concentrations in the industrial wastes; therefore they were eliminated from consideration. Two solvents of interest with respect to hazard to the environment, toluene and xylene, were identified in significant concentrations in the paint manufacturing sludge and in the solvent refining sludge. A significant concentration of cresol was found in the tannery sludge. These organics were selected for inclusion in the analytical program associated with the test cell leachates resulting from these three industrial wastes. Tables 12 and 13 present the toluene and xylene concentrations found in the leachates from the test cells containing the paint manufacturing sludge and the solvent refining sludge, respectively. Table 14 presents the cresol concentrations found in the leachates from the test cells containing the tannery sludge.

In comparing the results of the organic analyses on the municipal waste leachates and the industrial waste leachates, it was found that the concentrations of the organics in the two leachates from each test cell were very similar. This is a result of the high volatility of the three organic contaminants being studied. The toluene, xylene, and cresol, absent in the MSW, migrated as vapor through the test cells into the municipal waste and were absorbed by the leachate. The concentrations found probably resulted from a combination of factors including availability, solubility, and environmental factors such as pressure and temperature.

Due to the migration of the organics into the municipal waste in each test cell and then into the leachate, one net contribution of contaminant from the industrial waste could be quantified. However, since the municipal waste probably did not contain appreciable amounts of these organics, the concentrations found in the leachates probably represent typical levels that would be found in the field under similar conditions. Toluene was the most prevalent of the organics in the leachates from the test cells containing the paint manufacturing sludge. The combined meta- and para-xylenes were the most prevalent in the solvent refining sludge leachates. The combined meta- and para-cresols were more prevalent than ortho cresol in the tannery sludge leachates. The concentrations of the three organics found in the leachates from the three industrial wastes are sufficiently high to represent a potential environmental hazard should they migrate into groundwater at a disposal site.

COMPARISON OF EP EXTRACT AND TEST CELL LEACHATE METALS ANALYSES RESULTS

As previously noted, the primary objective of this study was to assess how accurately the EP mimics leaching of an industrial waste with municipal waste leachate. Table 16 provides a summary of the analytical results from the EP extracts and the test cell leachates. Only those metals which were found in the industrial waste leachates in concentrations above ten percent of the EP maximum allowable concentrations are included. The concentration values presented for the test cell industrial waste leachates have been corrected for background by subtracting the concentrations found in the associated municipal waste leachates.

As indicated in Table 16, all of the metals concentrations found in the EP extracts are less than the respective concentrations found in the industrial waste leachates except for the chromium concentrations associated with

TABLE 16. COMPARISON OF METALS ANALYSES OF EP EXTRACTS AND TEST CELL INDUSTRIAL WASTE LEACHATES

Waste type and metal contaminant	Concentration in EP extract (mg/ℓ)	Highest average concentration in test cell leachate* (mg/ℓ)
Oil reclaiming clay		
Cr	<0.001	2.62
Pb	0.002	1.26
Petroleum refining incinerator ash		
Cr	88.3	136.
Paint manufacturing sludge		
Cd	0.0051	0.328
Cr	<0.001	1.05
Hg	<0.0002	0.0416
Pb	5.83	604.
Tannery sludge		
Cr	2.20	0.521

* All values have been corrected for background by subtracting the concentrations found in the associated municipal waste leachate.

the tannery sludge. In three of the remaining seven cases, the metals concentrations in the EP extracts were less than the lowest reportable values while the concentrations in the industrial waste leachates were from 200 to 2000 times higher than the respective lowest reportable values. The chromium concentrations in the EP extract and industrial waste leachate from the petroleum refining incinerator ash were the most similar the concentration in the EP extract was approximately 65 percent of that in the leachate. For the other three cases, the metals concentrations in the EP extracts ranged from 65 to 600 times lower than the respective concentrations in the industrial waste leachates. In summary, the EP underestimated the highest concentrations found in the majority of the test cell industrial waste leachates. It should be noted however, that of the metals concentrations found in the industrial waste leachates above the maximum allowable concentrations (chromium from the petroleum refining incinerator ash and lead from the paint manufacturing sludge), the concentrations of these same metals found in the respective EP extracts were also above the maximum allowable concentrations. Thus, on a qualitative basis, the EP did predict which industrial wastes would present a potential hazard with respect to releasing metal contaminants at concentrations above 100 times the primary drinking water standards.

The reasons why the EP significantly underestimated many of the metals concentrations cannot be determined from this study, however, several potentially important factors were noted. The two industrial wastes for which the results indicate the worst predictions by the EP are from the oil reclaiming clay and the paint manufacturing sludge. As previously discussed, the paint sludge did not mix well with the water/acetic acid solution during EP testing. Although the oil clay appeared to disperse in the EP extraction solution during testing, the waste contained a large amount of oil which could have limited the wetting of the waste solids. As a result of the lack of intimate contact between the solids from these two industrial wastes and the EP extractant, the transfer of contaminants from the solids to the extractant solution was probably severely limited. This would have resulted in low concentrations of the metals in the EP extract. In the test cells, there was sufficient time for partial breakdown of the oil and other organics in the industrial wastes due to biological activity. This would have made the metal contaminants more available for transfer to the leachate. In addition, the chemical form or oxidation state of the metals might have been changed in the test cell environment making them more soluble.

The increase or decrease in solubility due to changes in chemical form or oxidation state may have effected the chromium concentrations found in the EP extracts and test cell leachates associated with the various industrial wastes. The relative chromium concentrations found in the extracts and leachates varied widely. The EP significantly underestimated the chromium concentrations in the leachates from the test cells containing the oil reclaiming clay and the paint manufacturing sludge. The EP only slightly underestimated the chromium concentration in the petroleum refining incinerator ash leachate while it overestimated by approximately four times the chromium concentration in the tannery sludge leachate. Since the exact form in which the chromium existed in the sludges is not known, and due to other limiting factors such as the one discussed above, it is difficult to directly relate the analytical results obtained to the oxidation states in which the chromium existed in each

sludge and the associated relative solubilities. In addition, the oxidation states and the solubilities of the chromium and the other metals in the leachates were probably effected by certain chemical characteristics of the test cell leachate including such factors as redox potential, buffer capacity, complexation capacity, and ionic strength. The study was not designed to assess the effect of each of these factors.

The assessment of how accurately the EP mimics the leaching of the industrial wastes in this study has so far been made without regard to the different solid-to-liquid ratios associated with the two leaching/extraction tests conducted. As specified in the EPA regulations, the EP was conducted using a total of 20 ml of extractant per gram of waste. No predefined solid-to-liquid ratio was established for the test cells since EPA was only interested in the highest contaminant concentrations identified in the leachate. In order to determine the effect of the different solid-to-liquid ratios and to see if the EP results more closely approximated the test cell results at the point where the ratios were identical, a summation of the total mass of chromium and lead leached from the test cells containing the petroleum refining incinerator ash and paint manufacturing sludge, respectively, was conducted. These are the two metals from the two sludges whose concentrations exceeded the EP maximum allowable concentrations. In each case, the total mass of metal leached over each collection and sampling period was summed until the total volume of leachate having passed through the industrial sludge reached 318 ℓ. This volume represents the same solid-to-liquid ratio used in the EP with respect to the 15.9 kg of industrial waste placed in each test cell. The concentrations of metals from the test cell industrial waste leachates used in the calculations were corrected for background. The results of the summation calculations are presented in Table 17.

The data presented include the total amount of each metal available in one kilogram of the respective waste, the total amount of metal leached from one kilogram of the waste in the EP and the test cells, and the percent of the

TABLE 17. EP AND TEST CELL COMPARISON OF TOTAL MASS OF METALS LEACHED AT IDENTICAL SOLID-TO-LIQUID RATIOS

Waste type and metal contaminant	Amount of metal available in waste (mg/kg)	EP		Test Cells	
		Amount leached (mg/kg)	Percent of available	Amount leached (mg/kg)	Percent of available
Petroleum refining incinerator ash					
Cr	7400	1766	23.9	1412	19.1
Paint manufacturing sludge					
Pb	17230	117	0.68	7164	41.6

Note: Solid-to-liquid ratio is 1 gm of waste to 20 ml of leaching solution.

available leached in the EP and the test cells. The total amounts of chromium leached from the petroleum refining incinerator ash were similar with 1766 mg/kg being leached in the EP and 1412 mg/kg being leached in the test cells. These values represent 23.9 and 19.1 percent of the available chromium, respectively. As previously discussed, the EP more closely estimated the highest average chromium concentration found in the petroleum ash test cell leachate than any metal in any waste tested. The EP concentration was approximately 65 percent of the highest average concentration in the leachate. With respect to the total amount of chromium leached at identical solid-to-liquid ratios, the EP leached approximately 125 percent of the amount of chromium leached from the petroleum refining incinerator ash in the test cells.

With respect to the paint manufacturing sludge, the EP leached only 117 mg/kg of lead from the waste while 7164 mg/kg of lead was leached from the waste in the test cells. The percent of the available lead leached were significantly different, 0.68 percent for the EP and 41.6 percent for the test cells. With respect to the total amount of lead leached at identical solid-to-liquid ratios, the EP leached only approximately 1.6 percent of the amount of lead leached in the test cells. With respect to the lead concentrations in the extract and leachate, the EP concentration was approximately 1.0 percent of the highest average concentration in the leachate.

In summary, the comparison of the total mass of metals leached at identical solid-to-liquid ratios resulted in a somewhat different relationship between the EP and test cell results than did the comparison of the metals concentrations in the EP extracts and test cell leachates. With respect to the chromium in the petroleum refining incinerator ash, the EP overestimated by approximately 25 percent the total mass of chromium leached from the waste in the test cells and underestimated the highest concentration found by approximately 35 percent. With respect to the lead in the paint manufacturing sludge, the EP underestimated the total mass of lead leached by 98 percent and the highest concentration found by 98.4 percent and 99 percent, respectively. Although the correlation between the EP and test cell results at identical solid-to-liquid ratios is different, it is not significantly better.

EVALUATION OF MUNICIPAL WASTE LEACHATE SAMPLERS AND OVERALL TEST CELL DESIGN

The inability of the municipal waste leachate samplers to provide sufficient leachate volumes for analysis was a matter of concern to the project personnel throughout the study. The test cell design was such that the samplers would theoretically intercept approximately 15 percent of the leachate moving through the municipal waste which should have resulted in a combined volume of 1.2 liters of leachate being collected each week for each test cell. This should have provided sufficient municipal waste leachate volumes over the sampling periods for analysis. When it was determined that the leachate samplers were not providing sufficient volumes under gravity-flow conditions, a small diameter collection tube was inserted through each external sampling port, through the associated teflon connector tube, and into the leachate sampler. A vacuum was applied to this smaller tube in an attempt to remove any leachate that might be trapped in the sampler and would not flow under gravity to the external sampling port. This procedure was, in most cases, not successful in producing much additional leachate. Therefore, it was deduced that either the samplers were blocked, the teflon connector tubes were leaking, the

leachate flow was not evenly distributed across the test cells, or a combination of all three.

There was no way to determine the nature of the problem while the test cells were in operation. After completion of the study, the test cells were carefully dismantled. Several things were noted that could have caused a reduction in the flow of municipal waste leachate into the samplers. Large pieces of paper such as dog food bags, grocery bags, and small boxes normally found in the household refuse were distributed around and above some of the collectors (as throughout the test cells) in sufficient quantities to partially divert the leachate flow. In a few instances, the epoxy paint covering both the samplers and the perforated plate on top of the samplers had softened to a sufficient degree to flow into the holes in the perforated plates and into the space between the perforated plate and the interior wall of each sampler. By forming a bond between the metal plate and the pea gravel on top of the plate, the paint had formed a seal across the top of the samplers which probably significantly restricted the flow of leachate into the samplers. The plates could not be removed from the samplers without first breaking the seal formed by the softened paint. The paint must have deteriorated as a result of some chemical activity during test cell operation because the paint was dry and not sticky prior to loading the test cells. A filamentous growth was observed in the samplers and gravel pack of the samplers in some of the test cells, particularly in those containing the paint manufacturing sludge. This growth was of sufficient density to have restricted the flow of the municipal waste leachate into the samplers. The teflon connector tubes were found to be intact and did not appear to have leaked. Thus, the failure of the samplers to collect sufficient leachate for analysis appears to have been the result of plugging of the samplers by partially deteriorated epoxy paint and to some extent by a biological growth, and by the diversion of leachate flow from the samplers due to large pieces of paper over and around the samplers.

As a result of these findings, several modifications in design should be considered if the test cells are to be used in further studies. First, the municipal waste leachate samplers should be modified to eliminate the plugging problems associated with the decomposition of the epoxy paint. For example, the perforated plates in the samplers could be replaced with ones constructed of a tough, reasonably inert, plastic or metal thus eliminating the need for the paint on the plates. It might be possible to eliminate the pea gravel placed on top of the perforated plates by moving the plates so they are flush with the tops of the collectors. The perforated plastic plates could then be covered with an inert screen material to prevent movement of municipal waste into the holes in the plates during compaction. This would probably help in limiting biological growth over the plates. Next, the municipal waste should be shredded to reduce the size of individual pieces of paper or other material that could divert leachate flow. This should provide for a more even distribution of leachate flow through the refuse and improved waste homogeneity in the test cells.

A better design of the test cells involves elimination of the three samplers incorporated in the municipal waste test cells. The test cells could be reconfigured to serve as municipal waste leachate generators only with the industrial wastes being contained in separate sealed leaching cells. In this

type of leaching system, the municipal waste leachate would collect in the bottom of the test cells and then flow by gravity or be pumped to a second small cell containing the industrial waste to be leached. Thus, the total volume of municipal waste leachate generated would be available for sampling which would probably provide a more representative leachate sample and thus better reproducibility of results between test cells. This would also eliminate the problems associated with the migration of volatile organic contaminants into the refuse and the resulting absorption in the municipal waste leachate. It should be noted that EPA has opposed this type of system in the past on the grounds that the municipal waste and industrial waste would not be in direct conduct. However, if the system were properly sealed to prevent contact between the leachate and the atmosphere, the results obtained for leaching of metal contaminants should be representative. Based on sample collection problems, WES advised Oak Ridge National Laboratory (ORNL) to use this type of collection system in their tests; such a system was employed by ORNL.

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APPENDIX

BULK ANALYSES OF THE INDUSTRIAL WASTES

Bulk analyses were conducted on duplicate samples of the five industrial wastes used in this study. The results of these analyses are presented in Tables A1-A5 in this appendix.

TABLE A-1. BULK ANALYSES OF OIL RECLAIMING CLAY

Parameter	Duplicates A (mg/kg)*	Duplicates B (mg/kg)
Arsenic	1.05	0.82
Barium	191.	+
Cadmium	1.04	1.53
Calcium	11200	14400
Chromium	14.7	16.9
Copper	23.7	26.9
Iron	5450	5050
Lead	664.	852.
Magnesium	4120	4680
Manganese	110.	115.
Mercury	0.06	<0.05
Nickel	7.58	8.33
Potassium	336.	282.
Selenium	0.50	<0.20
Sodium	317.	422.
Zinc	411.	551.
pH (standard units)	5.0	9.0
Cyanide	<5.0	<5.0
Ammonia (as N)	78.7	81.3
Total Kjeldahl Nitrogen	1500	1600
Nitrite + Nitrate	1500	2100
Total Phosphorus	840.	688.
Sulfide	<10.	<10.
COD	800000	810000
Oil & Grease	224000	216000
Petroleum Hydrocarbons	580000	565000
Phenols	56.2	59.8
Total Organic Carbon (weight %)	39.0	39.0
Total Solids (weight %)	56.4	59.8
Total Volatile Solids (weight %)	1.79	3.58

* All concentrations reported as mg/kg dry weight unless otherwise noted.

\+ Duplicate not analyzed.

TABLE A-2. BULK ANALYSES OF PETROLEUM REFINING INCINERATOR ASH

Parameter	Duplicates A (mg/kg)*	B (mg/kg)
Arsenic	33.8	32.5
Barium	136.	-+
Cadmium	2.46	2.50
Calcium	121000	113000
Chromium	7250	7550
Copper	396.	374.
Iron	24400	23800
Lead	645.	725.
Magnesium	22600	21900
Manganese	592.	610.
Mercury	<0.05	<0.05
Nickel	68.7	70.0
Potassium	2010	2090
Selenium	8.10	9.50
Sodium	37700	36300
Zinc	3910	3540
pH (standard units)	11.0	10.0
Cyanide	<5.0	<5.0
Ammonia (as N)	24.8	45.6
Total Kjeldahl Nitrogen	61.1	41.9
Nitrite + Nitrate	25000	15000
Total Phosphorus	1820	1400
Sulfide	<10.0	10.0
COD	6270	6000
Oil & Grease	760.	640.
Petroleum Hydrocarbons	10500	4980
Phenols	<2.0	<2.0
Total Organic Carbon (weight %)	<0.05	<0.05
Total Solids (weight %)	100.	100.
Total Volatile Solids (weight %)	<1.0	<1.0

* All concentrations reported as mg/kg dry weight unless otherwise noted.

\+ Duplicate not analyzed.

TABLE A-3. BULK ANALYSES OF PAINT MANUFACTURING SLUDGE

Parameter	Duplicates A (mg/kg)*	Duplicates B (mg/kg)
Arsenic	<0.05	<0.05
Barium	56500	- +
Cadmium	1.99	2.09
Calcium	9320	9920
Chromium	1740	1910
Copper	60.2	65.0
Iron	3480	2930
Lead	39600	53100
Magnesium	1170	1570
Manganese	73.2	64.6
Mercury	27.3	29.3
Nickel	11.4	13.8
Potassium	451.	484.
Selenium	0.60	0.40
Sodium	423.	472.
Zinc	2740	3190
pH (standard units)	7.0	7.0
Cyanide	<5.0	<5.0
Ammonia (as N)	105.	97.0
Total Kjeldahl Nitrogen	1875	2315
Nitrite + Nitrate	1100	1600
Total Phosphorus	474	547
Sulfide	10.	<10.
COD	120000	150000
Oil & Grease	7260	7520
Petroleum Hydrocarbons	23200	26000
Phenols	2.74	3.0
Total Organic Carbon (weight %)	40.0	38.0
Total Solids (weight %)	34.3	40.0
Total Volatile Solids (weight %)	<1.0	1.0

* All concentrations reported as mg/kg dry weight unless otherwise noted.

\+ Duplicate not analyzed.

TABLE A-4. BULK ANALYSES OF SOLVENT REFINING SLUDGE

Parameter	Duplicates A (mg/kg)*	Duplicates B (mg/kg)
Arsenic	<0.05	<0.05
Barium	3680	- +
Cadmium	<0.05	0.05
Calcium	116.	68.7
Chromium	0.50	<0.50
Copper	0.168	0.161
Iron	13.4	9.64
Lead	<0.50	<0.50
Magnesium	185.	91.6
Manganese	1.76	0.964
Mercury	<0.05	0.15
Nickel	<0.50	<0.50
Potassium	16.8	12.9
Selenium	0.20	0.20
Sodium	114.	95.6
Zinc	91.6	57.0
pH (standard units)	5.0	6.0
Cyanide	<5.0	<5.0
Ammonia (as N)	19.0	21.0
Total Kjeldahl Nitrogen	371.	409.
Nitrite + Nitrate	162.	179.
Total Phosphorus	<0.10	<0.10
Sulfide	<10.0	<10.0
COD	33000	27000
Oil & Grease	14200	27500
Petroleum Hydrocarbons	94000	73600
Phenols	12.0	11.5
Total Organic Carbon (weight %)	79.0	78.0
Total Solids (weight %)	39.0	35.8
Total Volatile Solids (weight %)	1.13	1.86

* All concentrations reported as mg/kg dry weight unless otherwise noted.

\+ Duplicate not analyzed.

TABLE A-5. BULK ANALYSES OF TANNERY SLUDGE

Parameter	Duplicates A (mg/kg)*	Duplicates B (mg/kg)
Arsenic	0.18	0.23
Barium	139.	+
Cadmium	<0.05	0.10
Calcium	17800	17700
Chromium	5320	7410
Copper	16.3	18.7
Iron	4130	5320
Lead	27.0	10.4
Magnesium	886.	856.
Manganese	59.1	67.7
Mercury	0.13	0.08
Nickel	5.06	6.47
Potassium	105.	114.
Selenium	0.20	0.80
Sodium	3430	3450
Zinc	34.6	36.8
pH (standard units)	9.0	9.0
Cyanide	11.6	5.00
Ammonia (as N)	5770	5930
Total Kjeldahl Nitrogen	12000	16400
Nitrite + Nitrate	5000	11000
Total Phosphorus	1130	965.
Sulfide	16.0	16.0
COD	110000	110000
Oil & Grease	6480	6160
Petroleum Hydrocarbons	55600	55000
Phenols	4.87	4.04
Total Organic Carbon (weight %)	13.0	10.0
Total Solids (weight %)	9.29	9.15
Total Volatile Solids (weight %)	1.36	<1.0

* All concentrations reported as mg/kg dry weight unless otherwise noted.

\+ Duplicate not analyzed.